Dr. Holetschek has tabulated the value of (l − L ± 180°) for every known comet, and the values obtained are as follows :—

(l − L ± 180°)	Number of elliptic comets.	Number of parabolic comets.	Total number with perihelion distances greater than 0·3.
0° to 30°	16	90	106
30 ,, 60	10	45	55
60 ,, 90	3	46	49
90 ,, 120	2	26	28
120 ,, 150	—	21	21
150 ,, 180	—	22	22
Total ...	31	250	281

It will be seen that the majority of all the known comets have the longitude of their perihelion at a small angular distance from that of the earth. This grouping is especially well marked in the case of elliptic comets of short period. The following table exhibits the results found for comets with perihelion distances less than 0·3 times the mean distance of the earth from the sun :—

l − L	Number of parabolic comets.
0° to 60	19
60 ,, 120	10
120 ,, 180	7
Total ...	36

Another interesting result brought out by Dr. Holetschek's investigations is that the positive sign occurs with very nearly the same frequency as the negative sign in the angle l − L ± 180°. This indicates that the perihelion points, when reduced to the ecliptic, lie, with equal frequency, in front of and behind the earth.

Mr. W. E. Plummer points out, in this month's *Observatory*, that the cause of the abnormal distribution exhibited by comets whose orbits are greatly inclined to the elliptic has still to be explained.

GASEOUS ILLUMINANTS.

I.

THE autumn course of Cantor Lectures at the Society of Arts was delivered by Prof. Lewes, who, after discussing the nature of various gases capable of burning with luminosity, gave a review of the theories which have been advanced to explain the light-giving power of certain flames.

Sir Humphry Davy first propounded his theory that the cause of luminosity in ordinary flames was the incandescence of nascent carbon—a theory which was accepted as the true one until the researches of Dr. Frankland in 1868, on the effect of pressure on non-luminous flames, showed that, under certain circumstances never likely to arise in a gas-flame, luminosity might be due to other causes. Later observers have shown that luminosity in a flame is to a great extent affected by temperature. These factors, though of the greatest importance, do not affect the truth of the original theory.

In the Philosophical Transactions for 1817, Sir Humphry Davy says, while alluding to a paper published in one of the early numbers of the *Journal of Science and Arts :* "I have given an account of some new results on flame, which show that the intensity of the light of flames depends principally upon the production and ignition of solid matter in combustion."

This definition, however, has been gradually altered until it is more often stated that "the presence of solid particles suspended in the flame (or in immediate contact with the burning gas) is essential to its luminosity"—an idea which Davy never had, as is shown by him later in the paper defining flame as follows: "Flame is gaseous matter heated so highly as to be luminous ;" and again : "When, in flames, pure gaseous matter is burnt, the light is extremely feeble." Moreover, he alludes to "common flames"—evidently meaning the flames of candles, lamps, or gas ; in all of which cases I think it can be proved beyond a doubt that his theory, as expounded by himself, was perfectly correct.

On June 11, 1868, Prof. E. Frankland read a communication before the Royal Society, in which he described experiments which led him to doubt Sir Humphry Davy's theory. He points out that the deposit of soot formed when a cold surface is held in a gas or candle flame is not pure carbon, but contains hydrogen, which can only be got rid of by prolonged heating in an atmosphere of chlorine. Also that many flames possessing a high degree of luminosity cannot possibly contain solid particles. Arsenic burnt in oxygen gives a bright white light ; yet as arsenic volatilizes at 180° C., and the arsenic trioxide forms at 218° C., it is evident that at the temperature of incandescence (which is at least 500° C.) there can be no solids, but simply vapours present in the flame ; and for the same reason, the intense light resulting from the burning of phosphorus in oxygen cannot be explained by the solid particle theory. From these results, Dr. Frankland considers that "incandescent particles of carbon are not the source of light in gas and candle flames, but that the luminosity of these flames is due to radiations from dense but transparent hydrocarbon vapours ;" and he further shows that non-luminous flames, such as that produced by carbon monoxide and hydrogen, can, when burning in an atmosphere of oxygen, be rendered luminous if the ordinary atmospheric pressure is increased to 10 atmospheres, so as to prevent or retard as far as possible expansion during combustion. From Dr. Frankland's experiments, there is no doubt that the luminosity of a flame is increased by pressing around it the atmosphere in which it is burning, and also that rarefaction has the opposite effect—a point also worked at by Davy ; but his experiments do not show that incandescent particles of carbon are not the principal source of luminosity in a gas-flame. He also shows that, the higher the density of the vapours present in a flame, the more likely is it to be luminous.

In 1874, Soret attempted to demonstrate the existence of solid particles in a luminous hydrocarbon flame, by focussing the sun's rays on the flame, and examining the reflected light by means of a Nicol prism ; but neither his research nor that of Burch, who repeated his experiments, using the spectroscope instead of the prism, showed more than that solid particles are present. Herr W. Stein, in considering Dr. Frankland's objections to Davy's theory, pointed out that the soot which is deposited from a candle or gas flame, and which Frankland looked upon as a condensed hydrocarbon, contains 99·1 per cent. of carbon and only 0·9 per cent. of hydrogen, which is about the quantity of hydrogen one would expect to be occluded by carbon formed under these conditions, and he also pointed out that if the soot were a heavy hydrocarbon condensed by a cold surface, cooling the vapour present in the flame, it ought to again become volatile at a high temperature, which it does not. The next steps in the controversy were the attempts made by Hilgard, Landolt, and Blochman, to trace the actions taking place in various flames by withdrawing the gases from different parts of the flame and determining their composition.

The experiments so made show that of the ordinary constituents of the gas the hydrogen is the first to burn, as one would expect from its relatively low igniting point and great rapidity of combustion. The burning of the carbon monoxide cannot be traced in the same way, as it is formed more rapidly (by the incomplete combustion of the marsh gas) than it burns, so that a steady increase in the proportion present takes place while the marsh gas steadily burns away, until a height of 1½ inches is attained, when its combustion becomes very rapid. Practically the illuminants do not undergo any change at first—indeed, they slightly increase in quantity from the decomposition by heat of some of the marsh gas into acetylene. They only begin to decompose at a height of 1½ inches above the orifice of the burner ; and then burn rapidly in the highest part of the flame. Moreover, a most important fact to be noted is that at the height of 1½ inches there is a sudden rise in the quantity of carbon monoxide at the moment that the illuminating olefines begin to disappear—a result undoubtedly due to the action of the nascent ignited carbon on carbon dioxide.

The illuminants in the flame consist of various hydrocarbon gases and vapours which in the lower part of the flame are reduced by the heat to simpler hydrocarbons, and finally in the luminous zone become decomposed to methane and carbon ; and it is the carbon in excessively minute particles which at the moment of liberation is heated to incandescence, and "principally" gives the light of the flame—the marsh gas originally present, and also that formed from the heavier hydrocarbons, adding its quota to the luminosity by still further decomposition during combustion, and finally becoming carbon dioxide and water. In 1876, Dr. Karl Heumann made a most important contribution to the theory of luminous flames in some papers published in *Liebig's Annalen*, in which he carefully went over the work of previous observers, and, by a large number of original experiments, proved that Davy's theory was correct, but that other causes also affected the degree of luminosity in a gas or candle flame.

In the ordinary atmospheric burner in which a mixture of coal gas and air burn with a non-luminous flame, it was supposed that the admixture of air, by supplying oxygen to the inner portion of the flame, caused immediate and complete oxidation of the hydrocarbons, without giving time for the liberation of carbon in the flame, and consequently luminosity. More modern researches, however, have proved this to be utterly wrong. The loss of luminosity is due to two causes—first, to the diluting action of the air introduced; secondly, to the fact that when a gas is so diluted, it requires a far higher temperature to break up the hydrocarbons present than when the gas is undiluted, and therefore the temperature which serves to liberate carbon and render the undiluted gas-flame luminous, is totally insufficient to do so in the diluted gas. Consequently the hydrocarbon burns to carbon dioxide and water without any such liberation, and hence with a non-luminous flame. The truth of this theory can be easily proved by the fact that diluting the gas with nitrogen, carbon dioxide, or even steam, serves to render it non-luminous, and therefore more rapid oxidation has very little or nothing to do with it, while the non-luminous flame can again be rendered luminous either by heating the mixture of air and gas just before combustion, or by heating the air with which the gas is diluted. This being so, it is evident that in the non-luminous flame we have the same hydrocarbon present as in the luminous flame; and anything that will tend to break them up, and liberate the carbon before the hydrocarbons are consumed, should again make the flame luminous.

That heat will do this has been already shown; but it can be demonstrated in a still more striking way. It is well known that chlorine gas and bromine vapour will both support the combustion of a gas containing much hydrogen, but that the combustion is very different from that of the same gas burning in air, as the chlorine or bromine, having no affinity for the carbon, combines with the hydrogen only, and deposits the carbon in clouds of soot; in other words, at the temperature of flame, chlorine will break up the hydrocarbons and liberate solid carbon. If now a small quantity of chlorine is led into the non-luminous Bunsen flame, it at once becomes luminous, proving conclusively that luminosity is due to solid particles of carbon liberated in the flame. Again, Heumann points out that a small rod held in the luminous flame becomes rapidly covered on its lower side with a deposit of soot; that is to say, the soot is present in particles in the flame, and the uprush of the gas drives it against the rod and deposits it there. If the soot were present in the flame, as Frankland supposed, in the state of vapour, and the rod merely acted by cooling and condensing it, the soot should be deposited on all sides of the rod; while a still further proof is, that if the soot existed as vapour in the flame, then, if the rod were heated to a high temperature, no soot should be deposited on it, whereas the soot deposits on a heated surface just as well as on a cool one.

It has been objected to the "solid particle" theory that, if it were true, solid carbon particles introduced into a non-luminous flame should render it luminous and make it look like an ordinary gas flame, whereas it simply gives rise to a cloud of sparks. But it must be remembered that the "nascent" carbon, as it is liberated from the decomposing hydrocarbons, is in the molecular condition, and has a very different degree of coarse-grainedness to any preparation of charcoal or lampblack we can make; and that, although our finest particle is a mass which takes so long to burn that it leaves the flames only partly consumed, and is projected into the air as a spark, the molecular particles of carbon are consumed as soon as they are rendered incandescent, and a steady luminosity, free from sparks, results. It is possible, however, to make the particles in a luminous flame roll themselves together, when they can be either deposited in a very coarse kind of soot, or be seen as glowing sparks and particles in the mantle of the flame. This can be done when two luminous flames are allowed to rush against each other or against a heated surface. Heumann also shows that the luminous mantle of a flame is not altogether transparent, and that the thicker the flame-layer, and the greater the number of solid particles contained in it, the less transparent does it become. If a non-luminous flame—say, hydrogen—is charged with the vapour of chromyl dichloride (CrO_2Cl_2), chromic oxide is produced; and this flame, which undoubtedly contains solid particles, is quite as transparent as the hydrocarbon flame. Finally, those flames which undoubtedly owe their luminosity to the presence of finely-divided solid matter produce characteristic shadows when viewed in sunlight; the only luminous flames which do not throw shadows being those which consist of glowing vapours and gases. Luminous gas flames, oil-lamp flames, and candle flames produce strongly-marked shadows in sunlight, and therefore contain finely-divided solid matter; and that this can be nothing but carbon is evident from the fact that all other substances capable of remaining solid at the temperature of the flames are absent.

From these considerations it is evident that Sir Humphry Davy's theory as propounded by himself is perfectly true as regards the ordinary illuminating flames.

In the second lecture, Prof. Lewes pointed out that, in the various analyses of illuminating gases, the heavy hydrocarbons are, as a rule, expressed as "illuminants," and were formerly considered to consist mainly of ethylene. This is an idea which the researches of the last few years have shown to be totally erroneous, as, besides ethylene, there is undoubtedly present benzene, propylene, butylene, and acetylene, and probably such members of the paraffin series as ethane, propane, and butane, while under certain circumstances, crotonylene, terene, allylene, and others, are present. The determination of the illuminants is therefore by no means the simple process one would imagine it to be from the directions given in most text-books on gas analysis.

The illuminants present in any given sample of coal gas depend upon (1) the kind of coal used, (2) the temperature at which it is distilled, and (3) the length of time the gas is in contact with the heated sides of the retort, as well as with the liquid products of the distillation.

Having dealt with this part of the subject at considerable length, Prof. Lewes went on to criticize the various methods of gas analysis, showing that all analyses of coal-gas have hitherto been founded on the idea that the "illuminants"—*i.e.* the heavy hydrocarbons responsible for the illuminating power—could be absorbed by fuming sulphuric acid, chlorine, or bromine. This, however, he said, is undoubtedly not the case. Mr. Wright has shown that, when coal gas has been treated with this acid, the residual gas still retains from 32 to 55 per cent. of its original luminosity; and although this may, to a certain extent, be owing to the methane, which at high temperature becomes slightly luminous, it is certain that a considerable percentage is due to the higher members of the paraffin series which are not absorbed by the acid, and which the methods of analysis usually employed utterly fail to detect. Indeed, given a gas containing any member of the paraffin series other than methane, the analytical results are not only incorrect, but misleading, as the percentages of hydrogen and methane present will be absolutely nullified by a very small quantity of the higher hydrocarbons.

All researches on the composition of coal gas point to the presence of ethane, and probably of higher members of the marsh gas series; while in carburetted gases they are undoubtedly present to a far higher extent. Ethane, propane, and butane have all been shown to be present in small quantities; and as ethane gives double, propane three times, and butane four times its own volume of carbon dioxide, it is evident that exploding with oxygen and taking the volume of carbon dioxide as representing marsh gas will undoubtedly give too high results with ordinary coal gas, while with a carburetted gas it will render the whole analysis useless. Moreover, the free oxygen is next absorbed, and the remainder taken as nitrogen; and the volume of gas after absorption by Nordhausen acid, less the marsh gas and nitrogen, is taken as representing the hydrogen in the gas. The result is that the hydrogen is always far too low, not only because the volume of marsh gas is too high, but because the residual nitrogen, having to bear the brunt of all the errors of analysis throughout some seven or eight absorptions, is also nearly always too high. These palpable errors in the quantity of marsh gas and hydrogen also render worthless the calculations of the carbon and hydrogen density of the gas, on which great stress has been laid by previous observers. On the whole, therefore, it is not to be wondered at that no relation has been discovered between the carbon and hydrogen density and the illuminating value of the coal gas.

The method of analysis which Prof. Lewes finds best is as follows:—

Two of Stead's apparatus are taken and placed with the entrance tubes end to end, and filled—one with distilled water saturated with air, and the other with clean pure mercury. The gas to be tested is collected in one of the Stead absorbing tubes, over water, so as to be saturated; it is then transferred over mercury in the eudiometer tube of the second apparatus, and measured and passed into sodic hydrate, in order to absorb the small trace of carbon dioxide to be found in the highly-purified London gas. When present in only small traces, the amount of carbon dioxide lost by water saturation cannot be detected. After the absorption of the carbon dioxide, the gas is run into the second apparatus, and the oxygen estimated by absorption with alkaline pyrogallate, which must be strong and fresh, containing about 25 grammes of pyrogallic acid dissolved in 50 grammes of sodic hydrate in 200 c.c. of water. It is absolutely essential that the solution should be fresh, as after some time it will evolve a considerable amount of carbon monoxide. The heavy hydrocarbons have now to be estimated; and inasmuch as benzene is one of the most valuable illuminants in the coal gas, it would be of great value if any absorbent could be found that would separate the benzene and ethylene series. Unfortunately this does not exist as far as is known; the usual absorbents having the following drawbacks:—(1) Nordhausen sulphuric acid, in which sulphur trioxide has been dissolved until it will solidify on cooling, absorbs both ethylene and benzene, and therefore cannot be used to separate them. (2) Fuming nitric acid is a good absorbent for both series. (3) Bromine water acts far more rapidly on ethylene than on benzene, but undoubtedly does absorb a considerable quantity of the latter if left long in contact with a mixture of the two. (4) None of the foregoing affect methane in diffused daylight. The nearest approximate result is obtained by treating the gas first with strong bromine water, but not leaving it too long in contact with it, and then removing bromine vapour over sodic hydrate—the absorption being taken as the ethylene series; while the benzene is absorbed by fuming nitric acid or saturated Nordhausen acid—acid fumes being removed in the sodic hydrate tube before measurement over water. After absorption with nitric acid gas, is run back into the eudiometer, and measured over water. It is then passed into an absorption tube filled with a fresh solution of ammoniacal cuprous chloride. This must not be used for more than six determinations of an ordinary coal gas containing (say) 3 to 6 per cent. of carbon monoxide, or 3 of a carburetted water gas, as, after much carbon monoxide has been absorbed, the solution has a tendency to again give up small quantities of the gas. The gas is now returned to the mercury eudiometer tube; and, after measurement, it is passed into an absorption tube containing ordinary paraffin oil (previously heated until everything that will distil at 100° C has gone off), which absorbs ethane, propane, butane, and a good deal of the methane. The residue is then washed and mixed with oxygen, which has itself been analysed, so that the percentage of nitrogen and foreign gases in it is known, and the mixture exploded over mercury. The carbon dioxide formed is estimated; and its volume *plus* the volume of gas absorbed by the paraffin gives the volume of gases in the methane series. A fresh portion of gas is now taken over mercury, and is exploded with excess of analyzed oxygen. The carbon dioxide is absorbed by sodic hydrate, and the oxygen by pyrogallate; and the residue will be the nitrogen—the hydrogen being determined by difference. In this way an analysis of South Metropolitan gas shows—

	Hydrogen		47·9	
Illuminants	Ethylene series	approx.	3·5	Total Hydrocarbons 45·6 per cent.
	Benzene series		0·9	
	Methane series	by paraffin	7·9	
		by explosion	33·3	
	Carbon monoxide		6·0	
	Carbon dioxide		0·0	
	Oxygen		0·5	
	Nitrogen		0·0	
			100·0	

In such an analysis, the lecturer remarked, no pretence was made that the exact percentage of each illuminant was given, but the total of the hydrocarbons is accurate; and their rough subdivision gave a far clearer insight into the characters of the gas than the more pretentious and more faulty analysis upon which it has been customary to argue. He said it must be clearly borne in mind that he only put forward this scheme of analysis to meet the need now rapidly arising for a method which would show whether ordinary coal gas enriched by cannel, coal gas carburetted with either gasoline or oil gas, or coal gas enriched by highly carburetted water gas, was being dealt with. In the first case, the ethylene and benzene series would be found well represented, while the carbon monoxide was low; in the second, the amount of hydrocarbons in the methane series would have become greater, and if oil gas had been used, a small increase in carbon monoxide might also be noticed; while the presence of carburetted water gas at once brought up the quantity of carbon monoxide, and the methane series became more important illuminants.

Prof. Lewes went on to show that the light-giving value of the hydrocarbons present in coal gas varies very greatly, the illuminating power increasing very rapidly with the number of carbon atoms in the molecule; and concluded by fully discussing the effect which the various diluents present in coal gas had upon its illuminating value.

(*To be continued.*)

ON THE ORBIT OF α VIRGINIS.

PROF. H. C. VOGEL has contributed a further discussion o the orbit of α Virginis (Spica) to the *Astronomische Nachrichten*, No. 2995. The following is a translation of the greater part of his paper:—

"After the periodical approach and retreat of this star, which was suspected from last year's observations, had been proved by some spectrographic observations made this year, an examination of the spectrum has been made at every favourable opportunity. So far, it has been possible to observe Spica on twenty-four evenings, thus affording material which allows its period to be determined with a greater degree of accuracy. Before communicating the results of the measurements of the photographs it will be necessary to preface a few remarks relative to the accuracy attainable.

"In No. 2896 of the *Astronomische Nachrichten* I detailed the first results which were obtained by means of the new spectrograph. The measurements were then made on some stars with spectra of the second class, and the increased accuracy given to these observations by the fact that the measurements were not made on the $H\gamma$ line only, but on some exceedingly sharp lines in the neighbourhood, has been fully confirmed by the now completed measurements of all the stars of the second and third class accessible to the Potsdam instruments.

"In the case of stars of class I.*a*, however, in which the $H\gamma$ line is more or less broad and fuzzy at the edges, and there are no other lines near it, greater difficulties than I at first expected opposed themselves to the satisfactorily exact measurement of their spectra. At one time I had the intention of making the measurements, not on the hydrogen line, but on the better defined lines of another metal, such as magnesium, which possesses a strong line at 448 $\mu\mu$. I abandoned this intention, however, because by adopting this means a number of stars, in whose spectra the said line of magnesium is weak or invisible, must have been excluded.

"The absorption lines of hydrogen in star spectra show by their appearance the following four types:—

"(*a*) Dark lines, with somewhat undefined edges, *e.g.* Capella.

"(*b*) Broad dark lines, with somewhat undefined edges, *e.g.* Rigel.

"(*c*) Broad bands, gradually fading away, but with a more or less broad and well-defined maximum of intensity in the centre, *e.g.* Sirius.

"(*d*) Broad bands, undefined at the edges, without any remarkable maximum of intensity in the centre (Spica).

"The four types are graphically represented by the curves in the accompanying figure."

Prof. Vogel notes that when the maximum of intensity of the form (*c*) lies outside the line of comparison, the measurement of the distance between the two is attended with no special difficulties. When, however, the comparison line overlaps the line in the star spectrum under examination, or in the case of spectra of the form (*d*), special devices have to be used to determine the distance